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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
p.o.

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If no title is shown please refer to the description.
Si aucun titre n'est indiqué se référer à la description.)

Lithographic marker structure compliant with microelectronic device processing,
lithographic projection apparatus comprising such a lithographic marker structure
and method for wafer alignment using such a lithographic marker structure

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Lithographic marker structure compliant with microelectronic device processing, lithographic projection apparatus comprising such a lithographic marker structure and method for wafer alignment using such a lithographic marker structure.

5 Field of the invention

The present invention relates to a marker structure as defined in the preamble of claim 1. The present invention also relates to a lithographic projection apparatus comprising a device for wafer alignment which uses a marker structure as defined in the preamble of claim 27. Moreover, the present invention relates to a method for wafer alignment using a marker structure as defined in the preamble of claim 28.

Background of the invention

The present invention finds an application in the field of lithographic projection apparatus that encompass a radiation system for supplying a projection beam of radiation, a support structure for supporting patterning means, which serves to pattern the projection beam according to a desired pattern, a substrate table for holding a substrate; and, a projection system for projecting the patterned beam onto a target portion of the substrate.

The term "patterning means" as employed here should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- 25 - A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmission mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which

ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired;

- A programmable mirror array. One example of such a device is a matrix-addressable surface having a visco-elastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as non-diffracted light. Using an appropriate filter, the said non-diffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localised electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described here above, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required; and

- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as set forth here above.

Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper or step-and-repeat apparatus. In an alternative apparatus - commonly referred to as a step-and-scan apparatus - each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallisation, oxidation, chemical-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or

sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997,

5 ISBN 0-07-067250-4, incorporated herein by reference.

For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens".

Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, both incorporated herein by reference.

For a lithographic process an alignment of the wafer to be processed with the mask pattern on the mask should be as precise as possible for a correct definition of features on the substrate, which features all should have sizes within specified tolerances. To this end, the lithographic projection apparatus comprises a wafer alignment module which provides for alignment of the substrate with the mask and mask pattern within a given (specified) tolerance. The wafer alignment system typically performs the alignment based on optical means. The position of a wafer or a portion of a wafer is determined by measuring an optical response from an optical marker which is illuminated by an optical source: for example, a grating is illuminated by a laser beam, the laser beam diffracts from the grating, and one or more of the diffracted orders are measured by respective sensors, which are typically located on a reference plane. Using the output of the sensors the position of the wafer can be derived (relative to the reference plane).

In the prior art optical markers comprise a grating with a periodicity suitable for diffraction of impinging light with a wavelength well within the visible range of the

spectrum. A typical periodicity is 16 μm . The grating is typically constructed of lines and trenches. Typically, the line width and trench width are each 8 μm . In order to obtain sufficient diffracted light from the grating and to obtain well-defined diffraction maxima and minima, the grating must encompass a minimal number of lines and
 5 intermediate trenches. The size in the direction of the periodic structure is about 750 μm .

The grating may be a phase grating or phase marker which takes into account a phase difference between the phase of rays scattered at the upper surface of the grating and the phase of rays scattered at the lower surface of the grating.

10 Also, the grating may be an amplitude grating which only takes into account the periodic structure of the grating without any further phase difference relating to an upper or lower level in the grating. Typically, an amplitude grating or amplitude marker is constructed of a periodic structure of first and second elements, which have similar surface levels but different respective reflectance.

15 Optical markers are used during microelectronic device processing (or IC processing) along the full manufacturing line. During the front end of line (FEOL), markers are used for alignment during manufacturing of transistor structures. At a later stage during the back end of line (BEOL), markers are needed for alignment of metallisation structures, e.g. connect lines, and vias. It is noted that in both cases the
 20 integrity of the markers must be sufficient to meet the required accuracy of alignment.

During semiconductor manufacturing processes a wafer is subjected to a plurality of treatments such as annealing, etching, polishing, etc., which may likely cause roughness of a marker (a recessed area in the marker and/or warping of the marker). Such marker roughness causes an alignment error of the image which may contribute to
 25 an overlay error in the construction of a semiconductor device. Also, it is conceivable that during the subsequent stages of processing the quality of markers tend to diminish.

A disadvantage of prior art optical markers is that during IC processing it is difficult to control the phase depth of the optical marker. As a result, the intensity of diffracted light under a given diffraction angle may be low and even close to zero, and accurate
 30 measurement of the diffracted beam may be difficult or even impossible. The phase depth can be defined as the resolved height difference between a top surface of a line and a top surface of a trench in a grating under a given angle of diffraction. If under an angle of diffraction, where (under optimal conditions) a maximum of diffracted

intensity is expected, the phase depth equals half a wavelength of the applied radiation, interference between diffracted waves will result in a low or zero intensity.

Control of the phase depth during IC processing may be difficult due to process variations from wafer to wafer, and also across a single wafer.

5 A further disadvantage of prior art markers results from the dependence of marker properties as a function of the layer(s) below the marker. It is known that due to different optical behaviour of the various layers, as found in semiconductor devices, the contrast of the marker may vary, which results in variations of the diffracted intensity as function of the layer below.

10 Moreover, it is known that various processing steps may adversely influence the shape of alignment markers. Due to the effect on the shape, the alignment by such modified markers may comprise an error which can result from the fact that the modified shape of the marker changes the generated (pattern of) diffracted beams.

Furthermore, in the prior art, during BEOL processing, optical markers could be
15 detected under capping layers by virtue of the residual structure which was visible at the surface. However, due to application of planarisation processes such as chemical mechanical polishing (CMP), the option to use a residual marker structure for alignment in many cases has become impossible.

In the prior art, markers on a semiconductor substrate that comprise trenches filled
20 with tungsten, are subjected to a CMP process for removing tungsten from the surface and planarising the surface. Due to the CMP process the tungsten structures are either filled or underfilled. The extent of filling is related to the phase depth of an optical signal generated by the marker, i.e., two discrete phase depth levels exist. One level relates to filled tungsten structures which are shallow and have a small phase depth, the
25 other level relates to underfilled tungsten structures which are relatively deep and have a large phase depth. Small phase depth of the filled markers is undesirable since the alignment error caused by the small phase depth is relatively large leading to large variations in measured wafer quality. Also, the large phase depth does not guarantee that the alignment error is reduced; the phase depth may be such that extinction of the
30 optical signal results. Small variations in phase depth again lead to variations in measured wafer quality. Furthermore, no control over the phase depth is obtained.

The influence of optical markers on IC processing may lead to undesirable side effects due to the fact that the optical markers are inherently larger than feature sizes in

integrated circuits. In the prior art the minimum feature size of markers is in the order of 1 μm . In current microelectronic devices, the typical minimal feature size is about 100 nm (depending on the device generation). Since the marker usually consists of the same material as (part of) the devices, the presence of an additional marker area of a substantial size in the vicinity of a device may have an influence on the local processing rate for that device in a given processing step. For example, a chemical reaction in a reactive ion etching process or a chemical deposition process may be influenced by the presence of a large marker area due to some kinetic constraint, or due to a local deviation of the wafer temperature, etc. A size difference between marker and device feature may thus lead, for example, to modification of a processing step for devices located closely to a marker. Due to the modification of the processing a variation of device characteristics may occur across a die and/or a wafer.

Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The person skilled in the art will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

In the present document, the terms "radiation" and "projection beam" are used to encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm) and extreme ultra-violet (EUV) radiation (e.g. having a wavelength in the range 5-20 nm).

Summary of the invention

It is an object of the present invention to provide a marker structure that allows to correct the phase depth in such a way that negative interference within the diffraction pattern is prevented.

In a first aspect of the present invention, this object is achieved in a marker structure on a substrate for optical alignment of the substrate as defined in the preamble of claim 1, characterised in that the first structural element has a first reflecting surface on a first level and the second structural element has a second reflecting surface on a second

level, the second surface being an opaque layer,
 the second level of the second reflecting surface being arranged below the first level of
 the first reflecting surface, with a difference of the first and second level determining a
 phase depth condition for the diffracted light pattern,

5 wherein a recess is present in the opaque layer to modify the phase condition.

The recessed area changes the phase depth by an amount that a positive interference
 between diffracted rays occurs and a diffracted pattern with sufficient intensity is
 generated by the marker structure.

10 In a second aspect of the present invention, this object is achieved in a marker
 structure on a substrate for optical alignment of the substrate as defined in the preamble
 of claim 8 characterised in that the marker structure comprises in a first metal layer a
 first optical marker in a first ordering tone and in a second metal layer, located above
 the first metal layer a second optical marker in a second ordering tone,
 the second optical marker being located above the first optical marker,
 15 the second ordering tone being a reverse tone of the first ordering tone,
 and the second metal layer being separated from the first metal layer by an intermediate
 dielectric layer.

Advantageously, the variation of the diffracted intensity as a function of the
 underlying layer is reduced by the stacking of marker structures above each other. The
 20 intermediate dielectric layer can be tuned to have an optimal phase depth with positive
 interference.

It is a further object of the present invention to provide a marker structure that
 allows monitoring of processing-induced damage.

25 This object is achieved in a marker structure on a substrate for optical alignment of
 the substrate as defined in the preamble of claim 9, characterised in that the marker
 structure comprises a first periodic structure and a second periodic structure,
 the second periodic structure being adjacent and parallel to the first periodic structure,
 the first periodic structure comprising a plurality of first structural elements of a first
 material and a plurality of second structural elements of a second material, the first and
 30 second structural elements being arranged in a repetitive ordering, with the first width
 being larger than the second width,
 the second periodic structure comprising a plurality of the first structural elements of
 the first material having a third width and a plurality of the second structural elements

of the second material having a fourth width, the first and second structural elements being arranged in a repetitive ordering, the third width being equal to the second width and the fourth width being equal to the first width, and
the second structural element in the second periodic structure being located adjacent to
5 the first structural element in the first periodic structure in such a manner that the second periodic structure is complementary to the first periodic structure.

By means of a complementary structure which comprises a first periodic structure and a second periodic structure complementary to the first one, it is possible to monitor
by use of the alignment system if one of the structural elements within a periodic
10 structure is damaged by the IC processing sequence, since a diffraction pattern will change differently for the first periodic structure than for the second periodic structure when damage occurs on either the first or the second structural element within the first and the second periodic structure.

It is another object of the present invention to provide a marker structure that
15 overcomes the removal of a residual marker from a metallisation layer due to CMP processing of the underlying layer which includes the marker structure. This object is achieved in a marker structure as defined in the preamble of claim 12, characterised in that the marker structure is present in a metallisation layer,
wherein the first structural element consists of a first surface area portion having a first
20 surface state and
the second structural element consists of a second surface area portion having a second surface state,
the first surface area portion being related to a first buried marker element, and
the second surface area portion being related to a second buried marker element,
25 the first and the second surface state being related to variations in morphology of the metallisation layer being induced by the first buried marker element and the second buried marker element, respectively.

Advantageously, the metallisation layer is deposited in such a way that a difference
in surface state/morphology as a function of the underlying material is created in that
30 metallisation layer. The periodic variation of surface state/morphology of the surface is detectable by an alignment- and/or overlay system.

It is an object of the present invention to provide a marker structure that overcomes effects caused by a relatively large marker area on features of devices located in the vicinity of such a large marker.

This object is achieved in a marker structure as defined in the preamble of claim 16, characterised in that the first structural element comprises a plurality of primary lines and a plurality of first interposed lines, the plurality of primary lines comprising the first material and the plurality of first interposed lines forming a further periodic structure.

Advantageously, the structural elements that build the marker structure are each sub-divided in sub-elements which have a characteristic size comparable to the product feature size. By mimicking the feature size of the product more closely, size-induced processing effects are minimised.

Moreover, it is an object of the present invention to provide a lithographic projection apparatus which allows application of the marker structure as described above.

Furthermore, it is an object of the present invention to provide a method of alignment of a substrate in a lithographic projection apparatus which uses the marker structure as described above.

Brief description of drawings

Below, the invention will be explained with reference to some drawings, which are intended for illustration purposes only and not to limit the scope of protection as defined in the accompanying claims.

Figure 1 depicts a lithographic projection apparatus comprising at least one marker structure according to the present invention;

Figure 2 schematically shows a cross-sectional view of a prior art marker structure to illustrate the concept of phase depth;

Figure 3a schematically shows a cross-sectional view of a marker structure from the prior art in copper-damascene layers;

Figure 3b a cross-sectional view of a first embodiment of a marker structure according to the present invention;

Figure 3c a cross-sectional view of a second embodiment of a marker structure according to the present invention;

Figure 4 schematically shows a cross-sectional view of a second embodiment of a marker structure according to the present invention;

Figure 5 schematically shows a marker structure of a fourth embodiment of a marker structure according to the present invention in a perspective view;

Figure 6 shows a planar view of a marker structure according to a fifth embodiment of the present invention;

- 5 Figure 7a, schematically shows a cross-sectional view of filled and underfilled tungsten marker from the prior art before chemical-mechanical polishing of tungsten;

Figure 7b show a planar view of a tungsten marker structure in silicon dioxide from the prior art;

- Figure 7c shows a planar view of a tungsten marker structure in silicon dioxide
10 according to a sixth embodiment of the present invention;

Figure 8 shows a planar view of a marker structure according to a seventh embodiment of the present invention;

Figure 9 shows an application of a stack of markers in accordance with the seventh embodiment of the present invention.

Description of embodiments

Figure 1 schematically depicts a lithographic projection apparatus 1 comprising at least one marker structure according to a particular embodiment of the invention. The apparatus comprises:

- 5 - a radiation system Ex, IL, for supplying a projection beam PB of radiation (e.g. UV radiation). In this particular case, the radiation system also comprises a radiation source SO;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means (not shown) for
- 10 accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means PW for accurately positioning the substrate with respect to item PL;
- and
- 15 - a projection system ("lens") PL for imaging an irradiated portion of the mask MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (i.e. has a transmissive mask). However, in general, it may also be of a reflective type, for example (with a reflective mask). Alternatively, the apparatus may employ another kind of patterning

20 means, such as a programmable mirror array of a type as referred to above.

The source SO (e.g. a mercury lamp or an excimer laser) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer

25 and/or inner radial extent (commonly referred to as σ -outer and σ -inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

30 It should be noted with regard to figure 1 that the source SO may be within the housing of the lithographic projection apparatus (as is often the case when the source SO is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into

the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source SO is an excimer laser. The current invention and claims encompass both of these scenarios.

The beam PB subsequently intercepts the mask MA, which is held on a mask table
 5 MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means PW and interferometric measuring means, the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means (acting on mask table MT)
 10 can be used to accurately position the mask MA with respect to the path of the beam PB, e.g. after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realised with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in figure 1. However, in the case of a wafer stepper
 15 (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask
 20 image is projected in one go (i.e. a single "flash") onto a target portion C. The substrate table WT is then shifted in the X and/or Y directions so that a different target portion C can be irradiated by the beam PB; and
2. In scan mode, essentially the same scenario applies, except that a given target
 25 portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", e.g. the Y-direction) with a speed v , so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = M v$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having
 30 to compromise on resolution.

The interferometric measuring means typically can comprise a light source, such as a laser (not shown), and one or more interferometers for determining some information (e.g., position, alignment, etc.) regarding an object to be measured, such as a substrate

or a stage. In Figure 1, for example, one interferometer IF is schematically depicted. The light source (laser) produces a metrology beam MB which is routed to the interferometer IF by one or more beam manipulators. In case more than one interferometer is present, the metrology beam is shared between them, by using optics that split the metrology beam in various separate beams for each interferometer.

5 A substrate alignment system MS for alignment of a substrate on table WT with a mask on mask table T, is schematically shown at an exemplary location close to table WT, and comprises at least one light source which generates a light beam aimed at a marker structure on the substrate and at least one sensor device which detects an optical
10 signal from that marker structure. It is noted that the location of the substrate alignment system MS depends on design conditions which may vary with the actual type of lithographic projection apparatus.

Figure 2 schematically shows a cross-sectional view of a prior art marker structure to illustrate the concept of phase depth.

15 An optical marker structure typically comprises a grating with a periodicity P suitable for diffraction of impinging light with a wavelength λ well within the visible range of the spectrum.

It will be appreciated that it is not essential that the periodicity P be suitable for diffraction of light within the visible spectrum, and that the invention can be
20 implemented with a periodicity P suitable for shorter wavelengths or suitable for longer wavelengths. Where the term "light" is used in the present document, it is not limited to wavelengths within the visible spectrum but may encompass light of longer wavelength or shorter wavelength than visible wavelengths.

The grating consists of a series of lines 100, with interposed trenches 102. The
25 trenches 102 have a depth d_t with respect to the top surface of the lines 100. The periodicity P of the grating is composed of a line width P_I and a trench width P_{II} .

In Figure 2, an impinging light beam λ is directed in a direction substantially perpendicular to the surface of the substrate. Alternatively, a non-perpendicular inclination of the impinging beam may be used as well.

30 The marker grating from the prior art is a so-called phase grating. A diffraction pattern is schematically shown by two diffracted beams, each having a diffraction angle θ relative to the surface.

In the diffraction pattern the position of intensity maxima and minima is governed by the periodicity of the grating. When the wavelength λ of the impinging light is within the range of visible light, periodicity P may typically be $16\text{ }\mu\text{m}$ to obtain a diffraction pattern suitable for purpose of alignment. Typically, the line width and trench width are each $8\text{ }\mu\text{m}$.

In order to obtain sufficient diffracted light from the grating and to obtain an angular distribution (a diffraction pattern) of well-defined diffraction maxima and minima, the grating must encompass a minimal number of lines and intermediate trenches which are illuminated by the impinging light beam. In the prior art a marker comprises at least 10 trenches within the illuminated area.

The intensity of the diffracted beams is further determined by the depth of the trenches relative to the top surface of the lines. In a certain direction of diffracted light, the light rays scattered at the top surface of the lines and the light rays scattered at the bottom of the trenches must have a certain phase relation to obtain a positive interference between these light rays in that direction, independent from the periodicity P . The depth of the trenches relative to the surface of the lines must be such that positive interference will occur, else if the interference is negative, an extinction of the signal will occur. This is known as the phase depth condition.

In the phase grating the interference in the diffraction pattern can be schematically deduced as follows: under angle θ a first set of photons reflect on the top surfaces of the lines 100, while a second set of photons reflect at the floor of the trenches 102. In order to determine if in a given direction, indicated by diffraction angle θ , a intensity maximum or minimum will occur, the phase difference of photons originating from the line top surfaces and from the trench floors must be substantially zero or half a wavelength, respectively, at the propagation front PF.

For an optical marker structure on a semiconductor wafer the structure may be exposed to various deformations during the processing steps of the semiconductor wafer to form integrated circuits. Due to these deformations the phase depth d_t may change during manufacturing.

Figure 3a schematically shows a cross-sectional view of a marker structure from the prior art. In Figure 3a an optical marker structure OM on a substrate layer SL is shown which may be applied in BEOL IC processes for Cu-based micro-electronic devices. Such devices are typically manufactured by so-called Cu damascene process

technology, wherein copper structures are embedded in (optically transparent) dielectric material, appearing as a "floating marker". The optical marker 50 consists of a plurality of Cu line elements 104, embedded in dielectric material, wherein the dielectric material is shaped as a plurality of line elements 106. Typically, as known to persons skilled in the art, the dielectric material may consist of a stack of various separate dielectric layers. By consequence, the phase depth d_t of the marker 50 may be ill-defined due to variations in the thickness of various separate dielectric layers in the dielectric stack. Moreover, variations may exist across a die or a wafer. Thus, in a worst case, the intensity of the marker's signals as included in the diffraction pattern may be too weak for detection by the alignment tool. This may result in a marker reject or even a wafer reject during IC processing.

Figure 3b shows a cross-sectional view of a first embodiment of a marker structure according to the present invention.

A way to avoid extinction due to an incompatible phase depth is shown in Figure 3b. In Figure 3b entities with the same reference number refer to the same entities as shown in figure 3a. In the area of the semiconductor substrate (or in general an opaque layer) SL under the floating marker, a recess R1 is created in an FEOL process. This recess increases the phase depth and thus reduces the probability of negative interference between scattered light from the surface level and the level of the substrate or opaque layer.

As shown in Figure 3b the recess may be formed only under a portion of area covered by the floating marker, in which case two different phase depths are present one of which may yield a better usable diffraction signal of sufficient intensity.

Figure 3c shows a cross-sectional view of a second embodiment of a marker structure according to the present invention.

In a second embodiment, the recessed area is defined during a FEOL process only below a portion of the marker. As indicated in the right-hand side of Figure 3c, recesses R2 are formed only below the transparent portions of the marker. In the left-hand side of Figure 3c a recessed area R3 is formed only below the opaque portions of the marker. Again, two different phase depths are present, each of which may yield a usable diffraction signal of sufficient intensity.

It is noted that such a recessed area R2, R3 may be formed by using the mask of the marker and an appropriate lithographic process, with a positive or negative exposure, respectively.

5 The recessed area as shown in Figure 3b or 3c preferably adds about 200 - 300 nm to the phase depth.

Figure 4 schematically shows a cross-sectional view of a third embodiment of a marker structure according to the present invention.

10 A further disadvantage of prior art markers is due to the dependence of marker properties as a function of the layer(s) below the marker. It is known that due to different optical behaviour of the various layers, as found in semiconductor devices, the contrast of the marker may vary, which results in variations of the diffracted intensity as function of the layer below, i.e. the phase depth strongly varies as a function of the under-lying layer.

15 In a third embodiment according to the present invention, the phase depth is better controlled by defining a first optical marker OM1 in a first metal layer (by exposure and processing) in a first ordering tone, i.e., a given periodic repetition of a first structural element and a second structural element. Next, in a second metal layer stacked on the first one with at least one intermediate dielectric layer IDL, a second optical marker OM2 with the same first ordering tone but in reverse tone relative to the
20 first marker, is defined (exposed and processed). The reverse tone indicates that the second marker OM2 comprises the same periodic repetition as the first optical marker OM1, but the locations of the first structural element and the second structural element are exchanged relative to the first marker OM1.

25 By control of the intermediate dielectric layer IDL the phase depth can be controlled: i.e., a phase depth value is selected which yields a diffraction signal of sufficient intensity. Moreover, the space occupied by the markers within a scribelane of the wafer is strongly reduced by stacking optical markers.

30 It is noted that the thickness of IDL is determined by the IC processing parameters. If, accidentally, the thickness of IDL between the stacked markers corresponds to a phase depth which causes negative interference for both a "red" laser beam and a "green" laser beam (i.e., the phase depth $d_i \approx 2.5\lambda_{\text{red}}/n = 3\lambda_{\text{green}}/n$), the stacking of markers according to the present invention is not feasible, and markers OM1, OM2 have to be defined in a non-stacked mode, which disadvantageously occupies a larger

area on the substrate. Alternatively, for such a thickness of IDL, stacking of markers is still possible if a different laser beam wavelength may be used.

Figure 5 schematically shows a marker structure of a fourth embodiment of a marker structure according to the present invention in a perspective view.

5 Various processing steps during IC fabrication may adversely influence the shape of alignment markers. For example, the block shape of the lines in the optical marker structure may change due to a CMP step. Due to the CMP process the cross-section of lines becomes asymmetrical: the polishing rounds only one of the top edges, basically due to the (local) polishing direction.

10 Due to the effect on the shape, the alignment by such modified markers (rounded at one edge) may comprise an error which results from the fact that the modified shape of the marker results in a change of the diffraction pattern being generated. Typically, a modification of the shape of the marker results in a shift of the position of the diffraction peaks generated by the optical marker structure relative to the position of the peaks for the pristine marker shape. In the prior art, it was not possible to distinguish
15 between a genuine misalignment of a marker or a modification of the marker shape, since both events lead to a change of the diffraction pattern and/or peak positions in the pattern.

The optical marker structure according to the third embodiment provides a
20 possibility to check whether the shift of the pattern is due to misalignment of the marker or due to deformation of the marker induced by IC processing.

The optical marker comprises a first periodic structure PS1 in a first portion, and a second periodic structure PS2 in a second portion. The first and second periodic structures PS1 and PS2 are located adjacent to each other with their respective
25 periodicity running parallel in one direction.

The first periodic structure PS1 has the same periodicity as PS2 but its ordering of structural elements is complementary to the second periodic structure PS2. The first periodic structure PS1 consists of a plurality of first structural elements SE1 of a first material with a first width w_1 and a plurality of second structural elements SE2 of a
30 second material with a second width w_2 , which are arranged periodically.

The second periodic structure PS2 consists of a plurality of third structural elements SE3 of the second material with a third width w_3 and a plurality of fourth structural elements SE4 of the first material with a fourth width w_4 , which are arranged

periodically. Since PS1 is complementary to PS2, the first structural element SE1 is adjacent to the third structural element SE3 with the first width w_1 being equal to the third width w_3 , and the second structural element SE2 is adjacent to the fourth structural element SE4 with the second width w_2 being equal to the fourth width w_4 .

- 5 Further, the periodic structures PS1 and PS2 are each asymmetric: the first and second width differ from each other.

As an example, the optical marker structure may be arranged as a Cu damascene structure, with Cu as first material, and insulator as second material. In this structure, the periodic variation of the surface reflectivity due to the difference of the reflectivity of Cu and insulator, acts as a amplitude grating. Thus, for example SE1 and SE4
10 comprise Cu and SE2 and SE3 comprise insulator. The width w_1 of SE1 is equal to the width w_3 of SE3, and the width w_2 of SE2 is equal to the width w_4 of SE4.

It is noted however that such a marker may also be embodied in a metal-semiconductor structure or a metal-insulator structure. Also this complementary optical
15 marker structure can be formed by two complementary geometric gratings (i.e., lines and trenches) etched in the semiconductor substrate and located next to each other.

As known to persons skilled in the art, the use of complementary features in the marker structure results in a fixed signal (with zero level) during measurement. If the periodic structures PS1 and PS2 are substantially complementary, a first signal from the
20 first periodic structure PS1 will be the complement of second signal from the second periodic structure PS2. The first and second signal cancel each other, and the combined signal of first and second signal as measured by a sensor will have a substantially zero level.

Due to processing effects the structure as described above, the first periodic
25 structure changes in a different manner than the second periodic structure because of the different asymmetry of both structures. In the first periodic structure the metal lines SE1 have a different width w_1 than the width w_4 of the metal lines SE4 in the second periodic structure. Due to the difference in width of the metal lines and insulator lines in the respective structures PS1 and PS2, the change of the shape of the respective lines
30 will be different.

Due to this different modification of the two structures, the first signal from PS1 is no longer the complement of the second signal from PS2. By consequence, the

complementary grating will no longer display a zero level signal during measurement, instead a non-zero signal will be measured.

The occurrence of such a signal from the complementary optical marker structure indicates process-related influences on the marker. Thus the presence of processing-
 5 induced effects on other markers with similar periodicity and the drift of these effects can advantageously be monitored by this complementary optical marker structure.

Figure 6 shows a planar view of a marker structure according to a fifth embodiment of the present invention.

In certain IC metallisation processes, a buried marker (i.e., an optical marker
 10 structure below the metallisation layer) is still detectable due to a residual topography at the surface. In that case, the geometric shape of the marker structure i.e., the lines and trenches are still visible in the surface of the metallisation layer as elevated and low-lying regions, respectively.

However, in IC processing, chemical –mechanical polishing (CMP) is applied as
 15 planarisation technique for W contacts and vias. By CMP the top surface is flattened, and any residual topography is lost. It has become impossible to align using a residual marker structure in such a case.

In the fifth embodiment of the present invention, a marker structure is formed in the aluminium metallisation layer which acts as an amplitude marker structure. Figure 6
 20 shows a layer stack which is formed during BEOL processing: in the trenches a W contact is formed. By CMP the surfaces of the W contact and insulator Oxide are planarised. On the planarised surface an Ti adhesion layer is deposited. Next, Al is deposited by a hot metal deposition process. Finally, a capping layer of Ti/TiN is deposited. In figure 6 some exemplary values for the thickness of the respective layers
 25 are indicated.

The metallisation layer comprises a hot metal process (deposited by physical vapor deposition, typically at about 350 °C under UHV conditions). Due to the different grain growth of Al on the Ti adhesion layer covering W and covering silicon dioxide,
 30 respectively, a different surface state is created in the Al layer in dependence on the under-lying material. Above the W contacts or plugs the surface has a first surface state ST1, and above the oxide, the surface has a second surface state ST2.

Possibly, the Ti layer may have a different texture in dependence of the underlying material. This texture may influence the nucleation and grain growth of Al deposited

during a hot metal deposition process in a manner differently for the area covering W and the area covering silicon dioxide. The difference in surface state relates to a difference in morphology, i.e., texture and/or grain size of the metallisation layer in dependence of the underlying material. Alternatively, the different nucleation and grain growth of Al on W or Al on silicon dioxide may also be caused by differences in thermo-physical properties of the underlying material since the Ti layer is relatively thin.

In any way, due to whatever physical-chemical cause, the local difference in surface state is detectable by the alignment- and/or overlay-sensor system as a marker structure. It is noted that such a morphological marker structure is not limited to the specific structure described in figure 6. The metallisation layer may show a periodic variation of a surface state also due to some other underlying materials (processed by CMP) which form a periodic structure.

In the prior art, markers on a semiconductor substrate that comprise trenches filled with tungsten, are subjected to a CMP process for removing tungsten and planarising the surface of the substrate. Due to the combination of W-CVD and CMP the tungsten structures are either filled or underfilled. The extent of filling is related to the phase depth of an optical signal generated by the marker, i.e., two discrete phase depth levels exist.

One level relates to filled tungsten structures which are shallow and have a small phase depth due to the substantially complete fill up to the top of the structure.

The other level relates to underfilled tungsten structures which are relatively deep and have a large phase depth.

Small phase depth of the filled markers is undesirable since the alignment error caused by the small phase depth is relatively large leading to large variations in measured wafer quality. Also, the large phase depth does not guarantee that the alignment error is reduced: the phase depth may be such that extinction of the optical signal results. Small variations in phase depth again lead to variations in measured wafer quality.

Figure 7a shows a cross-sectional view of filled and under filled tungsten markers from the prior art, before W-CMP.

In a trench etched within a silicon dioxide layer, tungsten is deposited by a CVD process in blanket mode. Figure 7a illustrates that the width of the trench governs

whether the conformally grown tungsten layer fills the trench in a 'filled' or 'underfilled' mode.

During W-CVD with conformal growth characteristics, narrow trenches will become 'filled' trenches, while wide trenches will become 'underfilled'.

5 The bottom of the trench may be covered by a barrier layer.

Next, a CMP process is carried out to planarise the structure. In this manner, a metal (W) structure with a surface substantially on level with the silicon dioxide surface is formed. As a consequence the phase depth of the 'filled' structure is substantially zero. The 'underfilled' metal structure comprises portions (i.e., the side-walls) which are
10 substantially on level with the silicon dioxide surface, and a central portion which surface is well below the silicon dioxide surface level. After CMP, the central W portion has a given phase depth relative to the silicon dioxide surface level.

As known to persons skilled in the art, for a given depth of the trenches and for a tungsten deposition process with given processing parameters (i.e., a conformal W
15 layer with a given thickness is formed), the width of the trench determines whether a tungsten line will either be filled or underfilled. Thus, the phase depth will comprise two discrete levels as a function of the trench width. Furthermore, due to different resistance to CMP of tungsten and silicon dioxide, the CMP process can not be controlled very accurately.

20 As mentioned above, in a marker structure comprising underfilled metal marker lines the depth of the central portion of the metal line may be such that the phase depth is substantially zero: no control over the phase depth is obtained.

Figure 7b shows a planar view (TOP) and a cross-sectional view (SIDE) of a tungsten marker structure in silicon dioxide according to a sixth embodiment of the
25 present invention.

In the sixth embodiment of the present invention, the optical marker structure comprises tungsten sub-segments in the silicon dioxide lines.

As sub-segments a plurality of sub-trenches are formed in the silicon dioxide lines, with the length direction of sub-trenches extending in a direction parallel to the
30 periodicity P of the marker structure. Since the plurality of sub-trenches are periodically arranged in a direction which will be a so-called non-scanning direction during alignment procedures, the optical response on the periodic arrangement of the sub-trenches in that direction P_{sub} is not detected by an alignment- or overlay-sensor

system. The possible diffraction signal generated by (the periodicity of) the sub-trenches is directed in a direction perpendicular to the direction of the diffraction signal of the actual marker structure (i.e., the repetition of tungsten trenches and silicon dioxide lines), so this possible signal will be well outside of the detection region.

5 Again, in this sixth embodiment, the trenches and sub-trenches are filled with tungsten by a tungsten CVD process. Next, a CMP process is carried out to planarise the structure. Due to the presence of tungsten in the sub-trenches, the CMP process is in better control: . By using sub-trenches the area of the marker structure comprising filled structures with its specific resistance to CMP is relatively enlarged, which allows
10 polishing of the filled trenches to a given height with greater accuracy. By better controlling the polished height of the filled trenches relative to the level of the lower portions of the underfilled structures, the phase depth may be controlled. The height of the top level of the filled tungsten structure relative to the lower level of tungsten in the underfilled region may be adapted to obtain a desired phase depth. The phase depth
15 may be adapted by changing the spacing between the sub-trenches (and their number) in the silicon dioxide lines to change the relative area of filled W structures.

The width of the sub-trenches is double of the thickness of the conformal tungsten layer (which thus results in a completely filled sub-trench having a zero phase depth).

20 The influence of optical markers on IC processing may lead to undesirable side effects due to the fact that the optical markers are inherently larger than feature sizes in integrated circuits. In the prior art the minimum feature size of markers is in the order of 1 μm . In current microelectronic devices, the typical minimal feature size is about 100 nm (depending on the device generation). Since the marker usually consists of the same material as (part of) the devices, the presence of an additional marker area of a
25 substantial size in the vicinity of a device may have an influence on the local processing rate for that device in a given processing step. For example, a chemical reaction in a reactive ion etching process or a chemical deposition process may be influenced by the presence of a large marker area due to some kinetic constraint, or due to a local deviation of the wafer temperature, etc. A chemical mechanical polishing
30 process may be influenced by the presence of a large marker area due to some mechanical constraint (i.e., a higher or lower resistance to CMP) caused by the marker area.

A size difference between marker and device feature may thus lead to modification of a processing step for devices located closely to a marker. Due to the modification of the processing a variation of device characteristics may occur across a die and/or a wafer.

5 From the viewpoint of IC manufacturing, a change of dimensions of the marker's structural elements to have them correspond more closely to critical feature sizes in devices may overcome the problem of the size dependency of IC processes. However, a change of "line" and "trench" widths may also change the periodicity of the marker. This would adversely require a major effort to redesign alignment- and overlay-sensor
10 systems to comply with a new marker periodicity.

Moreover, since alignment systems use linearly polarised laser light, polarisation effects resulting from interaction with such a modified marker structure may adversely result in strongly reduced signal strengths in such alignment systems.

To overcome this size dependency of IC processes, it is recognised that the optical
15 marker structure from the prior art requires to be segmented in such a way that critical device features are better mimicked while the diffraction pattern generated by the modified marker structure remains substantially the same as for an unmodified marker from the prior art. Also, the alignment system is arranged in such a way that polarisation effects results in usable signal strength of measured signals.

20 Figure 8 shows a planar view of a marker structure according to a seventh embodiment of the present invention.

In the seventh embodiment of the present invention the first structural elements are sub-segmented in a plurality of primary lines L1 extending in a first direction D1, each primary line having a width comparable to critical feature sizes of a device. In between
25 the primary lines are interposed lines of a different material. The width of the primary and interposed lines is such that dense device structures with critical feature sizes are mimicked.

Further, the second structural elements in between the first structural elements are sub-segmented in a plurality of secondary lines L2 extending in a second direction D2,
30 with interposed lines of a different material in between. Again, the secondary lines and interposed lines have widths comparable to dense device structures with the critical feature sizes for devices.

The second direction D2 is perpendicular to the first direction D1.

The material of the primary lines and the secondary lines is typically the same, e.g., a metal, while the material in between the primary lines and in between the secondary lines may be a dielectric or semiconductor.

In the sub-segmentation the original periodicity P of the marker structure is
5 maintained to allow the application of the alignment sensors from the prior art.

It is further noted that the width of the primary line may or may not be equal to the width of a secondary line.

The alignment system uses a first laser beam with a first linear polarisation $E1$ and a second laser beam with a second linear polarisation $E2$. The wavelength of the first
10 laser beam differs from the wavelength of the second laser beam. For example, the first laser beam consists of red light, and the second laser beam of green light.

The first linear polarisation direction $E1$ is perpendicular to the second linear polarisation direction $E2$. Further, the first linear polarisation $E1$ is arranged in such a way that the line segments $L1$ in the marker lines allow a further transmission of the
15 first polarised light beam in order to form a diffraction pattern of the marker structure. Similarly, the second linear polarisation $E2$ is arranged in such a way that the line segments $L2$ in the intermediate marker elements allow a further transmission of the second polarised light beam to form a diffraction pattern of the marker structure.

Figure 9 shows an application of a stack of markers in accordance with the seventh
20 embodiment of the present invention. A further advantage of the structure of the seventh embodiment is the fact that at least two of such markers can be stacked on top of each other, without causing any interference between them. By stacking marker structures in subsequent layers, the needed estate for the marker structures in the scribelane can be significantly reduced. In the example of Figure 9 in such a stack, a
25 second marker $OM2$ is translated over half the periodicity P with respect to the first marker $OM1$, with the width of "lines" being equal to the width of "trenches". Due to the segmentation of the "trenches" and "lines" perpendicular to each other, the polarisation effect prohibits cross-talk between the upper and lower marker structure. When using the first and second laser beams with their mutual perpendicular
30 polarisation, the lower marker structure appears covered by the upper marker: the alignment system only detects the upper marker structure.

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Claims

1. Marker structure on a substrate for optical alignment of said substrate,
comprising a plurality of first structural elements and a plurality of second
structural elements, said first and said second structural elements being arranged
5 in a repetitive ordering of one first structural element located adjacent to one
second structural element, said marker structure having a periodicity (P) in an
ordering direction of said repetitive ordering, said first structural element having
a first width in said ordering direction, and said second structural element having
a second width in said ordering direction, said first and second structural
10 elements having a length direction extending perpendicular to said ordering
direction,
said optical alignment, in use, capable of:
 - providing at least one light beam directed on said marker,
 - receiving a diffracted light pattern diffracted by said marker on a sensor for
15 measurement of said pattern,
 - determining alignment information from said measurement, said alignment
information comprising information on a position of said substrate relative to
said sensor;characterised in that,
20 said first structural element has a first reflecting surface on a first level and said
second structural element has a second reflecting surface on a second level, said
second surface being an opaque layer,
said second level of said second reflecting surface being arranged below said
first level of said first reflecting surface, with a difference of said first and
25 second level determining a phase depth condition for said diffracted light
pattern,
wherein a recess (R1; R2) is present in said opaque layer to modify said phase
condition.
2. Marker structure according to claim 1, wherein said first structural element is a
30 line element (104) comprising a metal.
3. Marker structure according to claim 1, wherein said second structural element is
a line element (106) comprising a dielectric.

4. Marker structure according to claim 1, 2 or 3, wherein said recess is present under a portion of said marker structure.
5. Marker structure according to any one of the preceding claims 1-4, wherein said recess (R2) is created as a partial recess, said partial recess substantially being located under each of said second structural elements.
6. Marker structure according to any one of the preceding claims 1-4, wherein said recess (R2) is created as a partial recess, said partial recess substantially being located under each of said first structural elements.
7. Marker structure according to any of the preceding claims, wherein said metal is copper.
8. Marker structure on a substrate for optical alignment of said substrate, comprising a plurality of first structural elements and a plurality of second structural elements, said first and said second structural elements being arranged in a repetitive ordering of one first structural element located adjacent to one second structural element, said marker structure having a periodicity (P) in an ordering direction of said repetitive ordering, said first structural element having a first width in said ordering direction, and said second structural element having a second width in said ordering direction, said first and second structural elements having a length direction extending perpendicular to said ordering direction,
said optical alignment, in use, capable of:
 - providing at least one light beam directed on said marker,
 - receiving a diffracted light pattern diffracted by said marker on a sensor for measurement of said pattern,
 - determining alignment information from said measurement, said alignment information comprising information on a position of said substrate relative to said sensor;characterised in that
said marker structure comprises in a first metal layer a first optical marker (OM1) in a first ordering tone and in a second metal layer, located above said first metal layer a second optical marker (OM2) in a second ordering tone, said second optical marker (OM2) being located above said first optical marker (OM1),

said second ordering tone being a reverse tone of said first ordering tone, and said second metal layer being separated from said first metal layer by an intermediate dielectric layer (IDL).

9. Marker structure on a substrate for optical alignment of said substrate,
 - comprising a plurality of first structural elements and a plurality of second structural elements, said first and said second structural elements being arranged in a repetitive ordering of one first structural element located adjacent to one second structural element, said marker structure having a periodicity (P) in an ordering direction of said repetitive ordering, said first structural element having a first width in said ordering direction, and said second structural element having a second width in said ordering direction, said first and second structural elements having a length direction extending perpendicular to said ordering direction,
 - said optical alignment, in use, capable of:
 - providing at least one light beam directed on said marker,
 - receiving a diffracted light pattern diffracted by said marker on a sensor for measurement of said pattern,
 - determining alignment information from said measurement, said alignment information comprising information on a position of said substrate relative to said sensor;
 - characterised in that
 - said marker structure comprises a first periodic structure (PS1) and a second periodic structure (PS2),
 - said second periodic structure (PS2) being adjacent and parallel to said first periodic structure (PS1),
 - said first periodic structure (PS1) comprising a plurality of first structural elements of a first material and a plurality of second structural elements of a second material, said first and second structural elements being arranged in a repetitive ordering, with said first width being larger than said second width,
 - said second periodic structure (PS2) comprising a plurality of said first structural elements of said first material having a third width and a plurality of said second structural elements of said second material having a fourth width, said first and second structural elements being arranged in a repetitive ordering, said third

width being equal to said second width and said fourth width being equal to said first width, and

said second structural element in said second periodic structure (PS2) being located adjacent to said first structural element in said first periodic structure (PS1) in such a manner that said second periodic structure is complementary to said first periodic structure.

10. Marker structure according to claim 9, wherein said first material is conductor material and said second material is either a semiconductor or insulator material.

11. Marker structure according to claim 9 or 10, wherein said first material is copper, and said second material is a dielectric material.

12. Marker structure on a substrate for optical alignment of said substrate, comprising a plurality of first structural elements and a plurality of second structural elements, said first and said second structural elements being arranged in a repetitive ordering of one first structural element located adjacent to one second structural element, said marker structure having a periodicity (P) in an ordering direction of said repetitive ordering, said first structural element having a first width in said ordering direction, and said second structural element having a second width in said ordering direction, said first and second structural elements having a length direction extending perpendicular to said ordering direction,

said optical alignment, in use, capable of:

- providing at least one light beam directed on said marker,
- receiving a diffracted light pattern diffracted by said marker on a sensor for measurement of said pattern,

- determining alignment information from said measurement, said alignment information comprising information on a position of said substrate relative to said sensor;

characterised in that

said marker structure is present in a metallisation layer,

wherein said first structural element consists of a first surface area portion having a first surface state (ST1) and

said second structural element consists of a second surface area portion having a second surface state (ST2),

said first surface area portion being related to a first buried marker element, and
said second surface area portion being related to a second buried marker
element,

5 said first and said second surface state (ST1, ST2) being related to variations in
morphology of said metallisation layer being induced by said first buried marker
element and said second buried marker element, respectively.

13. Marker structure according to claim 12, wherein said metallisation layer
comprises a metal layer being deposited by a hot metal deposition process in a
metallisation processing sequence.

10 14. Marker structure according to claim 12 or 13, wherein said metallisation layer
comprises an aluminium layer.

15 15. Marker structure according to claim 13 or 14, wherein said metallisation
processing sequence further comprises at least one of a deposition of a Ti
adhesion layer, a deposition of a Ti/TiN capping layer and a deposition of a
passivation layer.

20 16. Marker structure on a substrate for optical alignment of said substrate,
comprising a plurality of first structural elements and a plurality of second
structural elements, said first and said second structural elements being arranged
in a repetitive ordering of one first structural element located adjacent to one
second structural element, said marker structure having a periodicity (P) in an
ordering direction of said repetitive ordering, said first structural element having
a first width in said ordering direction, and said second structural element having
a second width in said ordering direction, said first and second structural
elements having a length direction extending perpendicular to said ordering
direction,

25 said optical alignment, in use, capable of:

- providing at least one light beam directed on said marker,
 - receiving a diffracted light pattern diffracted by said marker on a sensor for
measurement of said pattern,
 - 30 - determining alignment information from said measurement, said alignment
information comprising information on a position of said substrate relative to
said sensor;
- characterised in that

said first structural element comprises a plurality of primary lines (L1) and a plurality of first interposed lines,
said plurality of primary lines comprising said first material and said plurality of first interposed lines forming a further periodic structure.

- 5 17. Marker structure according to claim 16, wherein said primary line comprises said first material and said first interposed line comprises said second material.
18. Marker structure according to claim 16 or 17, wherein said first material has a first resistance to chemical mechanical polishing, and said second material has a second resistance to chemical mechanical polishing,
10 said first resistance being different from said second resistance.
19. Marker structure according to claim 16, 17 or 18, wherein said further periodic structure extends in a second ordering direction perpendicular to said ordering direction.
20. Marker structure according to claim 16, 17 or 18, wherein said further periodic structure extends in a second ordering direction parallel to said ordering
15 direction.
21. Marker structure according to claim 19 or 20, wherein
said second structural element comprises a plurality of secondary lines (L1) and a plurality of second interposed lines,
20 said plurality of secondary lines and said plurality of second interposed lines forming a second further periodic structure in a third ordering direction perpendicular to said second ordering direction.
22. Marker structure according to any of the claims 16 to 21, wherein said primary lines and said first interposed lines have a dimension comparable to a critical
25 feature size of a product device being created on said substrate.
23. Marker structure according to claim 22, wherein said secondary lines and said second interposed lines have a dimension comparable to a critical feature size of a product device being created on said substrate.
24. Marker structure according to any one of the claims 16-23, wherein said light
30 beam from said at least one light source in said optical alignment has a first linear polarisation (E1) extending parallel to said second ordering direction.
25. Marker structure according to any one of the claims 20-24, wherein said optical alignment is further capable of:

- providing a second light beam directed on said marker,
 - receiving a second diffracted light pattern diffracted by said marker on a second sensor for a second measurement of said second pattern,
 - determining second alignment information from said second measurement, said
- 5 second alignment information comprising second information on a position of said substrate relative to said second sensor,
- wherein said second light beam from said second light source in said optical alignment has a second linear polarisation (E2) extending parallel to said third ordering direction.
- 10 26. A substrate for microelectronic devices comprising at least one marker structure according to any one of the preceding claims 1 – 25.
27. A lithographic projection apparatus comprising:
- a radiation system for providing a projection beam of radiation;
 - a support structure for supporting patterning means, the patterning means
- 15 serving to pattern the projection beam according to a desired pattern;
- a substrate table (WS) for holding a substrate;
 - a projection system for projecting the patterned beam onto a target portion of the substrate;
 - a substrate alignment system (MS) for detecting a position of said substrate
- 20 relative to a position of said patterning means;
- said substrate comprising at least one marker structure according to any one of the preceding claims 1 – 26.
28. Method of alignment of a substrate in a lithographic projection apparatus
- 25 comprising:
- a radiation system for providing a projection beam of radiation;
 - a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
 - a substrate table (WS) for holding a substrate;
- 30 - a projection system for projecting the patterned beam onto a target portion of the substrate;
- a substrate alignment system (MS) for detecting a position of said substrate relative to a position of said patterning means;

- said substrate comprising at least one marker structure according to any one of the preceding claims 1 – 27.

Abstract

A marker structure on a substrate for optical alignment of the substrate includes a plurality of first structural elements and a plurality of second structural elements. The first and the second structural elements are arranged in a repetitive ordering of one first structural element located adjacent to one second structural element, with a periodicity
5 in an ordering direction of the repetitive ordering. The first structural element has a first width in the ordering direction, and the second structural element has a second width in the ordering direction. Both structural elements have a length direction extending perpendicular to the ordering direction.

10 The optical alignment is capable of:

- providing a light beam directed on the marker,
- receiving a diffracted light pattern, diffracted by the marker, on a sensor for measurement of the pattern,
- determining alignment information from the measurement which relates to a position
15 of the substrate relative to the sensor.

The marker structure is manufactured by a lithographic process using a mask with a geometrical pattern for generating the marker structure.

The first structural element has a first reflecting surface on a first level and the second element has a second opaque reflecting surface on a second level, below the
20 first level of the first reflecting surface.

The difference of the first and second level determines a phase depth condition for the diffracted light pattern.

In the second opaque reflecting surface a recessed area is present to modify the phase condition.

25 [Figure 3b]

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Fig 1

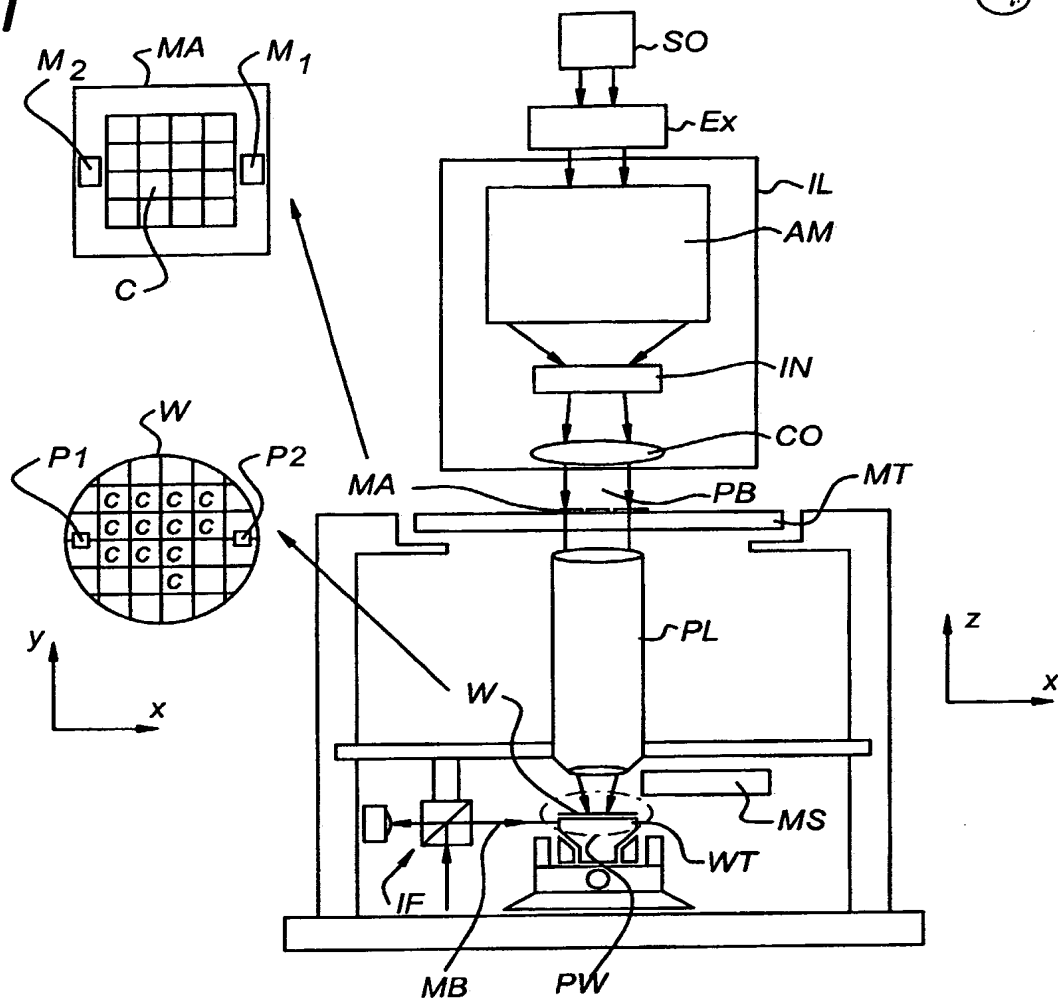


Fig 2

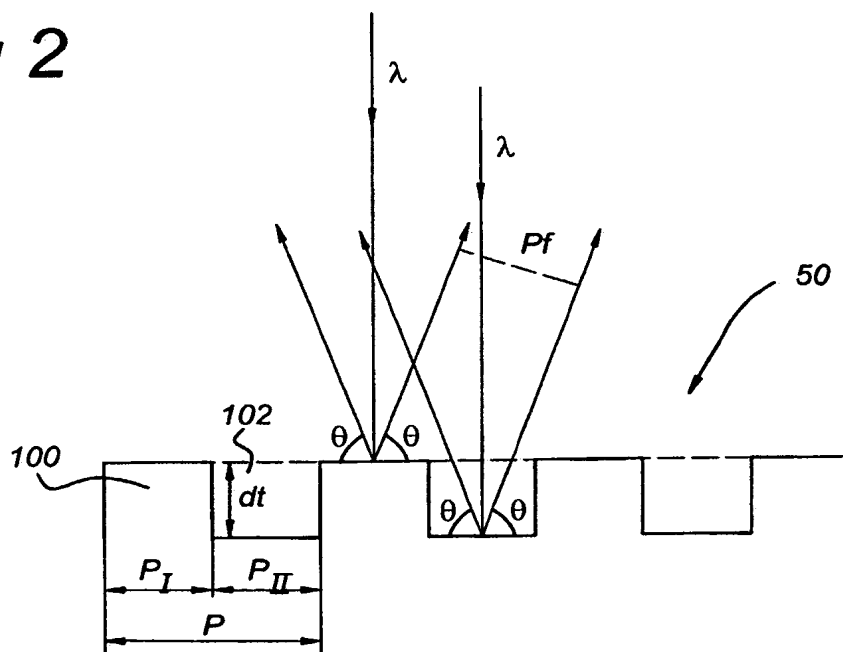


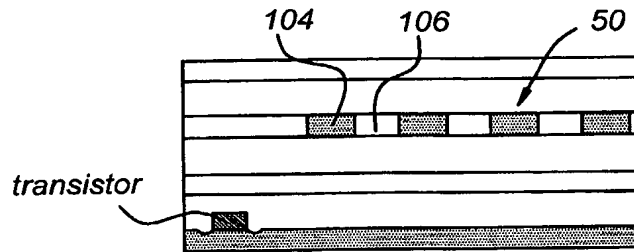
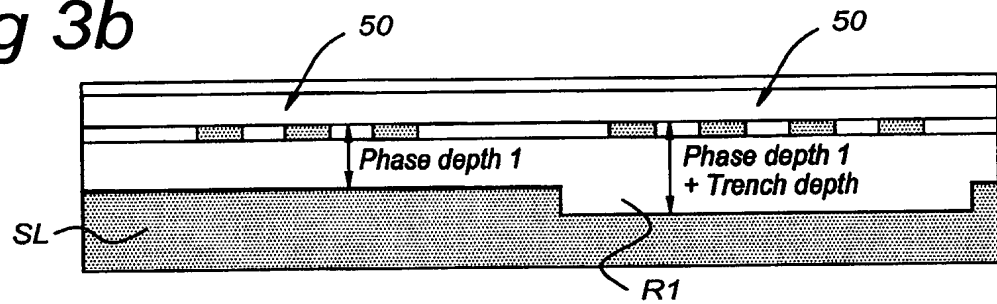
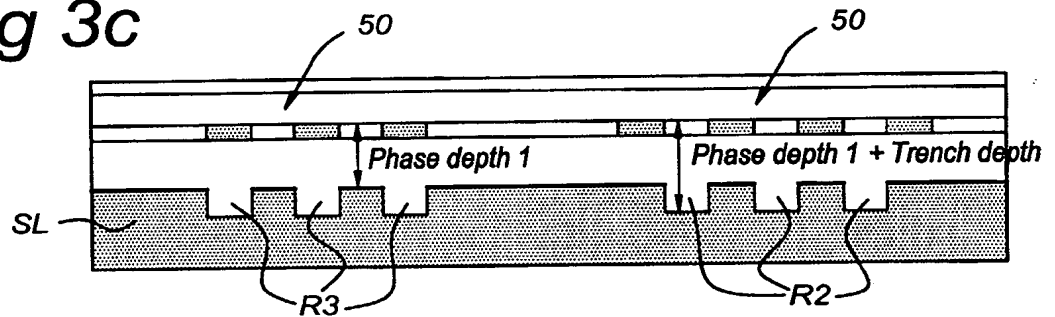
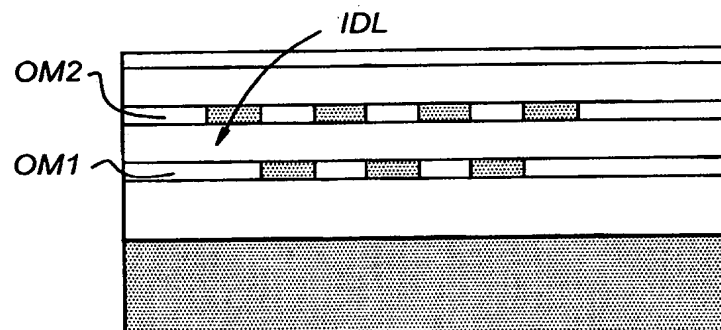
Fig 3a**Fig 3b****Fig 3c****Fig 4**

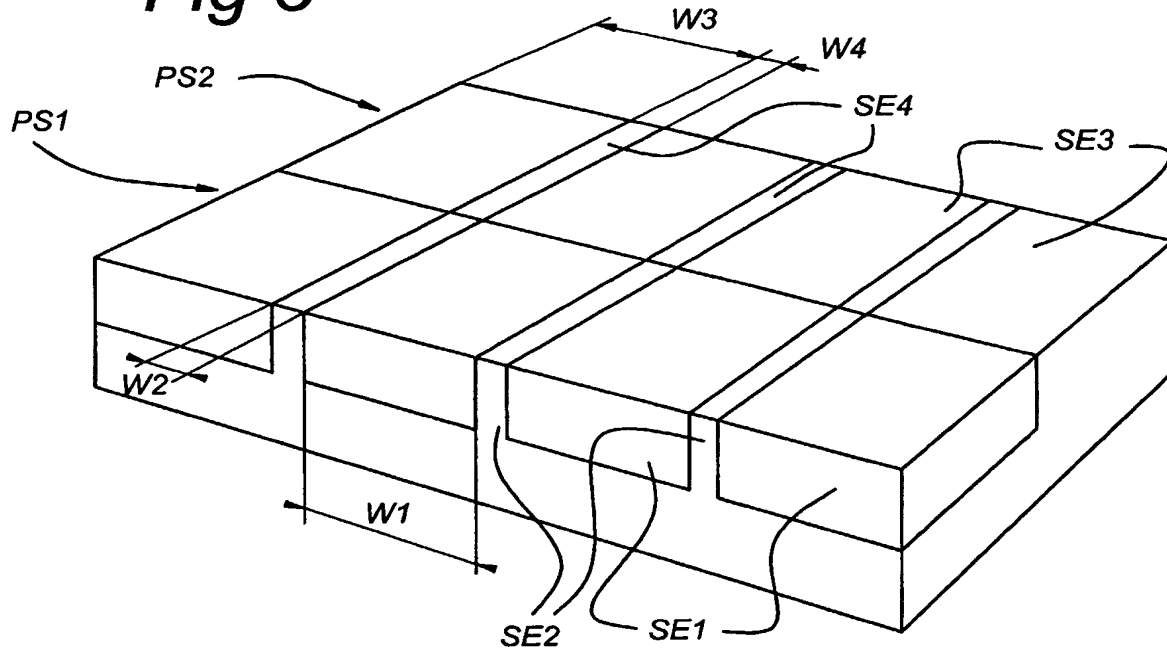
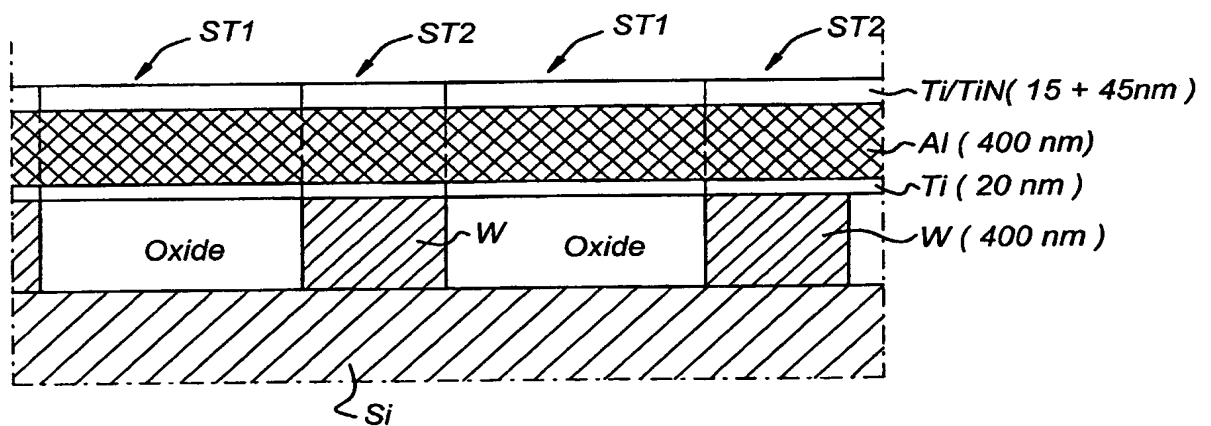
Fig 5**Fig 6**

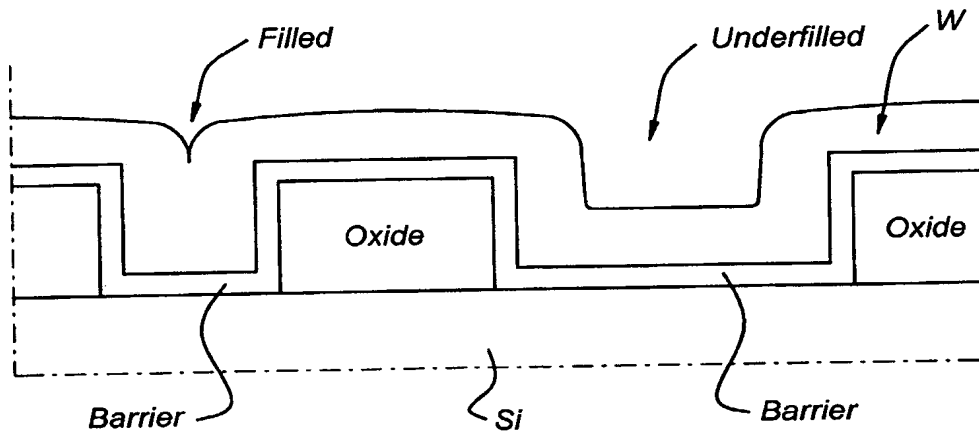
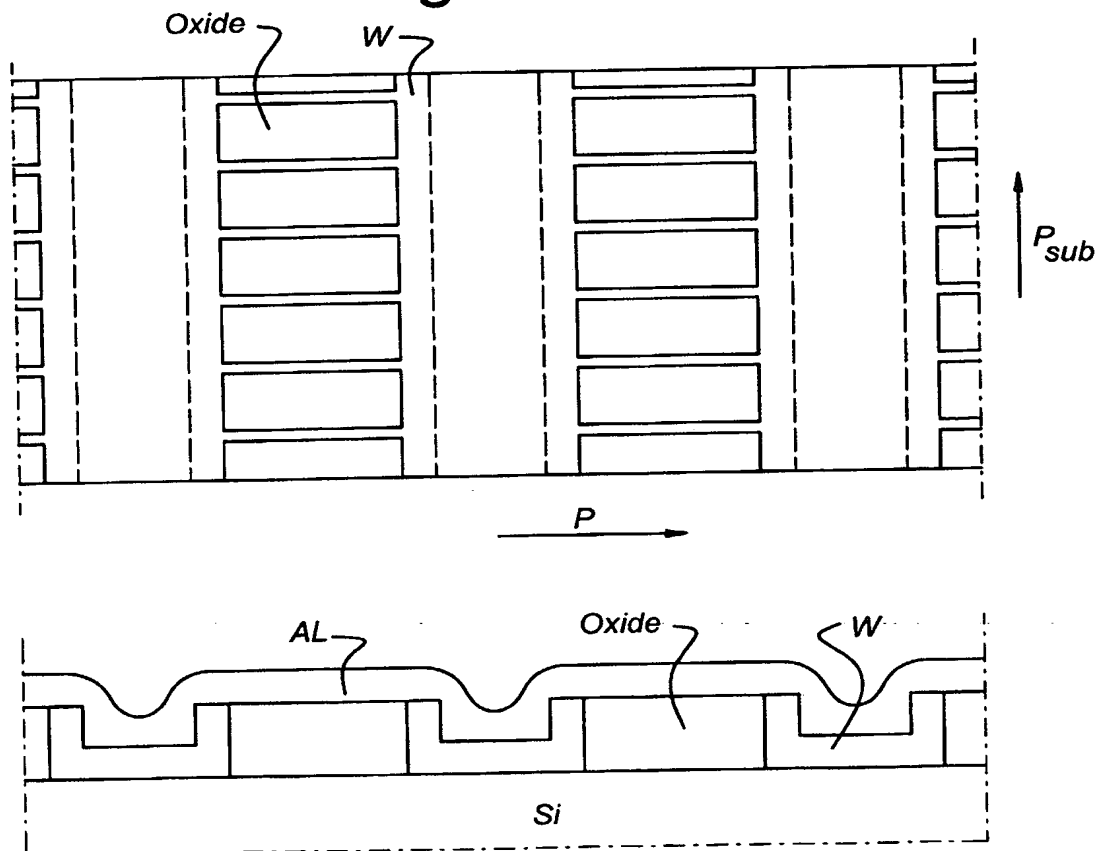
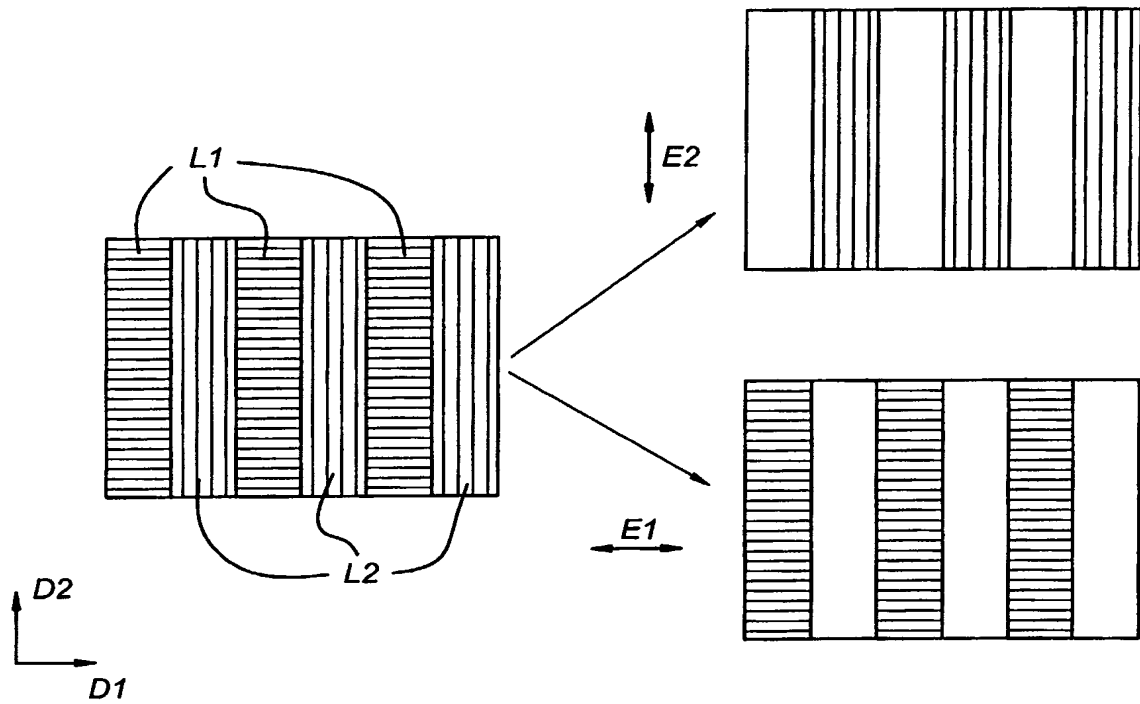
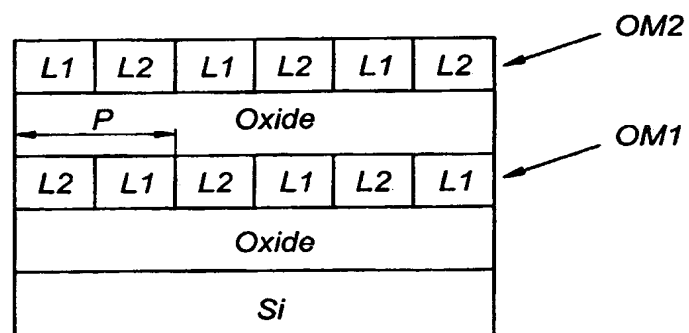
Fig 7a*Fig 7b*

Fig 8*Fig 9*

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